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SPACE ENVIRONMENTAL EFFECTS ON POLYMERIC MATERIALS

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INTRODUCTION

Polymer-matrix composites have considerable potential for use in the construction of orbiting structures such as the Space Station and space antennas because of their light weight, high strength, and low thermal expansion. However, they can suffer surface erosion by interaction with atomic oxygen in low-earth orbit and degradation and/or embrittlement by electrons and ultraviolet radiation especially in geosynchronous orbit. Thus, a study of the effect of these environmental hazards on polymeric materials is an important step in the assessment of such materials for future use in space.

ATOMIC OXYGEN

Atomic oxygen, which is the major atmospheric component in the low-earth orbit, is chemically very reactive. It can be generated in the laboratory by subjecting molecular oxygen at low pressure to radio-frequency radiation. In our study, atomic oxygen was generated in a chamber 4 inches in diameter and 6 inches long kept at a pressure of 200 millitorr. So that the products of the reaction of polymeric materials and atomic oxygen could be identified, three U-tubes were placed in the line between the chamber and the vacuum pump. The first tube was immersed in a dry ice/acetone bath, while the other two were immersed in liquid nitrogen. After a sample was exposed to atomic oxygen, the contents of each tube was analyzed separately by warming the tube to room temperature and transferring the contents to a

gas cell. The products were identified by infrared spectroscopy. In all cases, the first tube contained water (H_2O), the second tube contained carbon dioxide (CO_2), and the third tube had no measurable product. Polyimides also formed nitrogen dioxide (NO_2) and polysulfone formed sulfur dioxide (SO_2). In both cases, the extra product was found in the second tube. No other products could be identified, implying that the interaction of atomic oxygen with polymeric materials results in the formation of simple oxides of each element present.

Additional studies on atomic oxygen focused on the rate of interaction with various polymers and in developing polymeric systems which are more resistant to interaction with atomic oxygen. Table 1 shows the mass loss for various materials after exposure to atomic oxygen. It is clear that fluorinated materials are resistant to attack by atomic oxygen. It has also been shown that silicon-containing materials are similarly resistant.[1] To test the effectiveness of silicon-containing compounds in polymeric systems, polydimethylsiloxane (PDMS) was incorporated into two polymers; a polysulfone (P1700), and a polyetherimide (Ultem). Films of both systems were cast and samples of each were exposed to atomic oxygen. The results are shown in Table 2. Since the incorporation of PDMS in the polymer film was effective in reducing the attack by atomic oxygen, other silicon-containing compounds are currently being assessed.

It was shown on several Space Shuttle flights that the interaction of atomic oxygen with polymeric materials results in surface erosion.[2] We have employed diffuse reflectance infrared spectroscopy to study surface interactions. A graphite-Ultem composite was studied by comparing the diffuse reflectance infrared spectrum before and after exposure to atomic oxygen. The data show that certain chemical groups on the polymer interact more rapidly than others. Specifically, the carbonyl group seems to react most rapidly, followed by the imide and methyl groups. The benzene ring appears to react more slowly than the other groups. The structure of Ultem is shown in Figure 1.

ELECTRONS AND ULTRAVIOLET RADIATION

Irradiation by energetic electrons and ultraviolet radiation is the greatest environmental hazard to polymeric materials in the geosynchronous orbit. To assess the resistance of materials to these radiations, a unique apparatus was built at the NASA Langley Research Center. It consists of a chamber 9 inches in diameter and 9 inches high into which a sample can be mounted. The chamber can be evacuated to a pressure of 10^{-8} torr. An electron gun and a mass spectrometer are also incorporated in the vacuum system, and an ultraviolet lamp is positioned so that the sample can be irradiated with

electrons and ultraviolet radiation simultaneously or separately. The mass spectrometer can monitor the volatile products from the interactions of the radiations with the polymeric material. While some background problems have plagued the instrument, we have obtained some results for polysulfone. When this polymer is irradiated with either electrons or ultraviolet radiation, the mass spectrum shows peaks at mass 48 and at mass 64. These masses correspond to the chemical structures SO and SO_2. Other workers have shown that SO_2 is a product of irradiation of polysulfone.[3] The structure of polysulfone (P1700) is shown in Figure 2. This study will be extended to include measurements with infrared spectroscopy.

REFERENCES

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TABLE 1.

Mass Loss of Materials After Exposure to Atomic Oxygen

Material	Exposure Time (min.)	Mass Loss (mg)	% Loss
Graphite Fiber (HMS 34-1)	360	121	80.0
FEP Teflon	375	2.6	2.4
Polysulfone (P1700)	375	46.7	56.9
Polyetherimide (Ultem)	300	9.0	25.0

TABLE 2.

Polymeric Materials Containing Polydimethylsiloxane (PDMS) Exposed to Atomic Oxygen

%PDMS (by weight)	Exposure Time (min.)	Mass Loss (mg)	% Loss
	Polysulfone (P1700)		
0	180	5.8	8.8
0.43	180	3.2	6.5
0.89	180	2.2	5.6
	Polyetherimide (Ultem)		
0	360	24.2	29.0
1.35	360	12.5	13.1
4.31	360	12.7	12.8

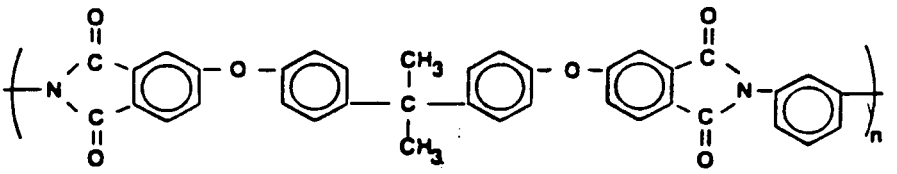

Figure 1. Chemical structure of polyetherimide (Ultem).

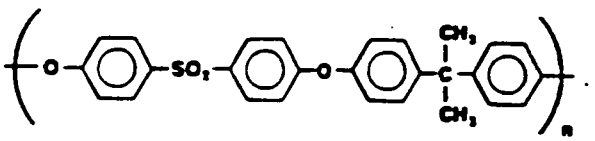

Figure 2. Chemical structure of polysulfone (P1700).